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MODELING GUN DYNAMICS WITH THREE-DIMENSIONAL BEAM ELEMENTS

DAVID A. HOPKINS

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The dynamic behavior of gun systems can be examined using finite element techniques to obtain approximate solutions to the equations of continuum mechanics. However, this approach may require many hours of both human and computer time to formulate the model and analyze the results. Models which use beam theory to describe a gun system are viable alternatives. Beam models capture the basic behavior of the gun system but require substantially less computer time to utilize. Other benefits are the ease with which geometric models can be generated and the simplicity with which existing models can be modified to incorporate new modeling thrusts. Described here are some basic issues in the development of a three-dimensional beam model. Application of a code implementing the method which illustrates how a tank gun system can be successfully modeled with a three-dimensional beam model is then presented. The results are compared with predictions from DYNACODE-G/P, Little Rascal, and with experimental data.

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1. INTRODUCTION

The initial conditions of the free-flight regime for a projectile launched from a gun tube are determined by the pressure loading on the base of the projectile and the loads induced by interaction between the gun tube and the projectile during the in-bore travel regime. Substantial research, both analytic and experimental, has been conducted in an effort to gain a basic understanding of these loads during the in-bore travel regime. This research has led to the development of several gun system models which are useful in predicting the launch conditions of a projectile (Erline and Kregel 1988; Soifer and Becker 1987; Rabern and Bannister 1990). The complexity of the gun system model appropriate in any analysis depends upon considerations of asymmetries in the gun system, detail of information desired about the gun system, the intended use of the results, and the ease of implementing the modeling technique selected. Typically, modeling approaches can be organized into three levels of complexity.

The simplest models conceptually are two-dimensional beam models. These models do not allow coupling between the axial, torsional, and transverse directions. Reasonable predictions for the gun tube motion can be obtained provided the coupling in the gun system between in-plane and out-of-plane motion is not significant. The Little Rascal (Erline and Kregel 1988) gun dynamics model is an example of this approach. The information available from this model describes the gun system component's displacements and velocities and the loads applied to these components. The simplicity of a two-dimensional model allows it to be quickly implemented for various specific models of gun systems. However, this same simplicity dictates that details concerning the stresses and strains in the components are generally not obtainable.

The other end of the modeling spectrum is represented by complex finite element models of gun systems. The use of DYNA3D (Hallquist 1983) in analyzing gun tube and projectile motion during the in-bore cycle illustrates the application of this approach in modeling a gun system. The primary drawback in using this approach is the substantial commitment of time and resources in both pre- and post-processing of the data and in the solution phase of the analysis. Also, while the resultant model provides desired detailed information about the local behavior of the components, extracting information of a more general nature, such as the overall muzzle motion of a gun tube, can be difficult.

Three-dimensional beam models provide a bridge between these two approaches. A standard characteristic of these models is the allowance of six degrees of freedom (DOF) in the motion of the gun system—three translational and three rotational. Like two-dimensional beam models, three-dimensional beam models are simple to develop and employ. However, unlike two-dimensional models they are also capable of modeling coupling between the displacements and rotations of gun system components. This can be accomplished in two ways. First, the equations of motion may be coupled by the selection of a particular beam theory. Second, the interface models which describe the interactions between gun system components produce in-plane displacements that cause out-of-plane loads. Such coupling can be important in determining how interactions between gun system components affect overall gun system performance. This report describes the development process of a three-dimensional beam model.

2. MODELING PROCESS

An overview of the modeling process is shown in Figure 1. The steps in this process can be divided into six phases. These phases are

(1) Modeling of the gun system component geometry
(2) Derivation of the governing equations
(3) Development of the loading models
(4) Formulation of the system model
(5) Solution of the system equations
(6) Analysis of the results.

In this hierarchy, each phase determines the options available in the next phase. For instance, the selection of a particular geometry for a gun system component determines the form of the governing equations which describe the behavior of that component. In the following sections, each of these phases is discussed in detail. The goal of this process is the development of a modeling approach applicable to a three-dimensional beam model.

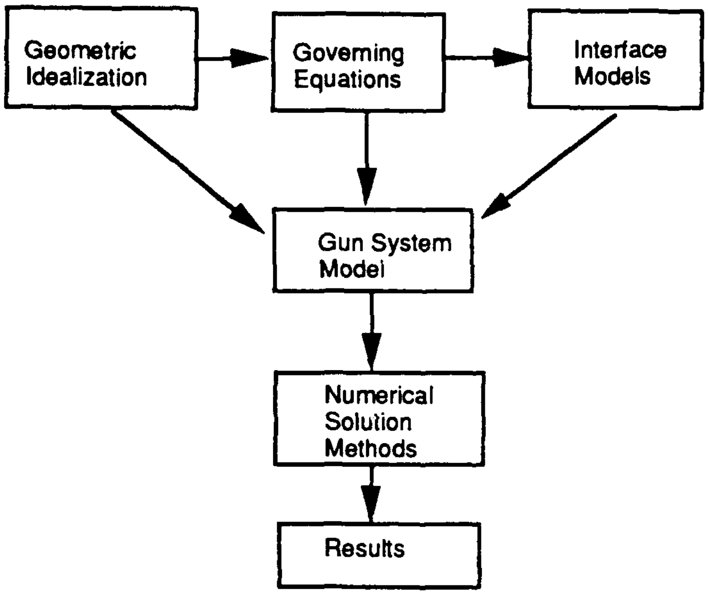

Figure 1. Modeling Process.

3. GEOMETRY

The first step in the modeling process is the selection of an appropriate geometric idealization for each component of the gun system. Consider a fictitious gun tube represented by Figure 2(a). The actual geometry of the tube can be idealized in several ways, which are shown in Figures 2(b), 2(c), and 2(d). These figures will be referred to as models 1, 2, and 3, respectively. It is seen that the geometry of the tube can be easily described by the use of beam segments. The use of beam segments means that the geometric variables needed to describe the system are

A : Cross-sectional area

L : Length of the beam segment

x_i : a set of parameters describing the shape of the cross-section

I_{xx}, I_{yy}, I_{zz} : the planar moments of inertia of the cross-section

P_{xy}, P_{xz}, P_{yz} : the planar products of inertia of the cross-section.

The area and the mass moments of inertia can be determined from the cross-section variables, x_i, and the length, L, respectively. This means that the number of parameters required to describe the

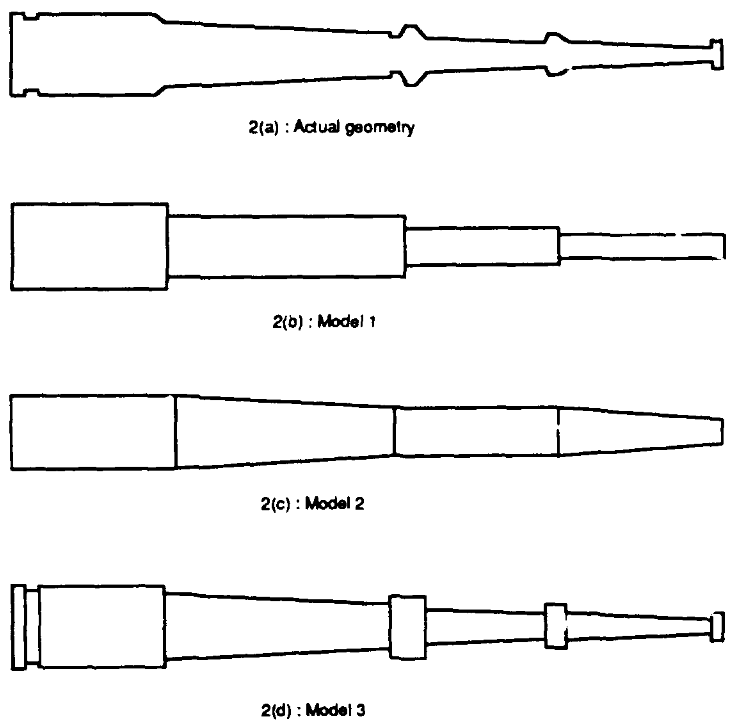

Figure 2. Gun Tube Representations.

geometry can be reduced. Such a simplification has a significant impact upon the ease with which a model can be developed.

Consider now the various idealizations of Figure 2. In model 1, the tube is represented as four interconnected beam segments. Each beam segment is assumed to have constant cross-sectional properties. The use of constant cross-sectional properties, such as the area, means that these properties will generally be discontinuous between adjacent beam segments. Another representation of the gun tube is shown in model 2. Again the tube is modeled by four beam segments, but now a linearly tapered beam segment is utilized. The use of tapered beam segments allows a more accurate representation of the gun tube physical properties. Finally, in model 3, a still more accurate model of the tube geometry is obtained by employing short beam segments. This modeling approach may require many more segments than models 1 or 2, but will provide a better estimate of the properties of the tube. Any of these idealized geometries can be implemented in a gun system model. However, the geometry selected determines the appropriate form of the governing differential equations of motion which are used to describe the gun system.

4. GOVERNING EQUATIONS

In this phase, the governing differential equations for the model are determined. In the beam model to be developed, six degrees of freedom (DOF), three translational and three rotational, are desired. This places restrictions upon the form of the governing equations. The form of the governing equations will be further restricted by the particular geometric model selected in phase 1. Each of the idealized models leads to a different set of governing equations.

For model 1, Bernoulli-Euler (B-E) beam theory with constant coefficients is sufficient. This theory is the simplest available which allows six DOF. This theory can also be used for model 2 by simply allowing variable coefficients in the governing equations. For both models, the equations of motion can be written

$$\frac{\partial}{\partial x}\left(EA\frac{\partial u}{\partial x}\right) = \rho A\frac{\partial^2 u}{\partial t^2}\,; \tag{1}$$

$$\frac{\partial}{\partial x}\left(GJ_p\frac{\partial \theta}{\partial x}\right) = \rho J_p\frac{\partial^2 \theta}{\partial t^2}\,; \tag{2}$$

$$\frac{\partial^2}{\partial x^2}\left[\left(EI_{yy}\frac{\partial^2 w}{\partial x^2}\right) + \left(EI_{yz}\frac{\partial^2 v}{\partial x^2}\right)\right] = -\rho A\frac{\partial^2 w}{\partial t^2} + p_w(x,t)\,; \tag{3}$$

$$\frac{\partial^2}{\partial x^2}\left[\left(EI_{zz}\frac{\partial^2 v}{\partial x^2}\right) + \left(EI_{yz}\frac{\partial^2 w}{\partial x^2}\right)\right] = -\rho A\frac{\partial^2 v}{\partial t^2} + p_v(x,t)\,, \tag{4}$$

where the coefficients may be functions of the axial coordinate x. Model 3, though, utilizes short beam segments. Consequently, a beam theory which includes transverse shear effects is more appropriate than B-E theory. Simple Timoshenko beam theory is an example of a beam theory that may be used to describe the transverse equations of motion (Shames and Dym 1985). This would include the effects of the transverse shear without overly complicating the governing equations. The axial and torsional equations of motion would not change. Experience and experiments indicate that for a gun tube, B-E theory provides an adequate representation of the tube. Because of this, model 3 will not be considered further. Instead, discussion is limited to the use of B-E theory in modeling a gun system. Examining equations 1-4, it is seen that the axial and torsional equations of motion are uncoupled both from each other and from the transverse equations of motion. Furthermore, if the coordinate system is selected such that the axes are principal axes, then the equations of motion in the transverse directions are also uncoupled. Neglecting the slight curvature of the tube centerline, gun tubes have circular cross-sections. Therefore, the transverse equations will not be coupled through the left-hand sides. The governing equations thus reduce to four uncoupled linear differential equations which describe the motion of a beam segment. A variant of B-E theory has been formulated in which the divergence of the bore centerline from a straight line is considered (Kingsbury 1985). The equations of motion resulting from this approach are fully coupled even when the axes are principal axes. This modified beam theory can be used for either model 1 or 2. Use of this theory requires the description of the actual tube centerline in the model description. For the eccentricities of typical gun tube centerlines, the increase in predictive capability does not at present justify the use of these more complex governing equations in a gun dynamics model.

Finally, it is re-emphasized that the equations of motion to be used are in a sense not necessarily three-dimensional. Although they allow six DOF, the equations presented reduce to two one-dimensional equations of motion in the axial and torsional displacements and two two-dimensional equations of motion in the transverse displacements.

What then justifies calling this model a coupled three-dimensional model? This question is answered by considering the form of the interface models which describe how the gun system components interact.

5. INTERFACE MODELS

The purpose of an interface model is to describe the manner in which either the separate components of a gun system, such as the gun tube and projectile, interact, or how external loads are applied to a particular gun system component. These loading routines determine the right-hand sides of equations 1-4, the loading functions. For either model 1 or model 2, these interface models are thus the only possible source of three-dimensional coupling since these equations are otherwise uncoupled.

It is beyond the scope of this report to fully derive a detailed gun tube/projectile interface model such as the one used in SHOGUN. However, a simplistic model of gun tube/projectile interaction due to balloting is easily formulated which illustrates a basic difference between two and three-dimensional interface models for balloting. Balloting occurs when the outside diameter of the bourrelet of a kinetic energy projectile is smaller than the inside diameter of the gun tube through which it is fired. A simple model of the bourrelet consists of replacing the bourrelet by a linear spring as depicted in Figure 3.

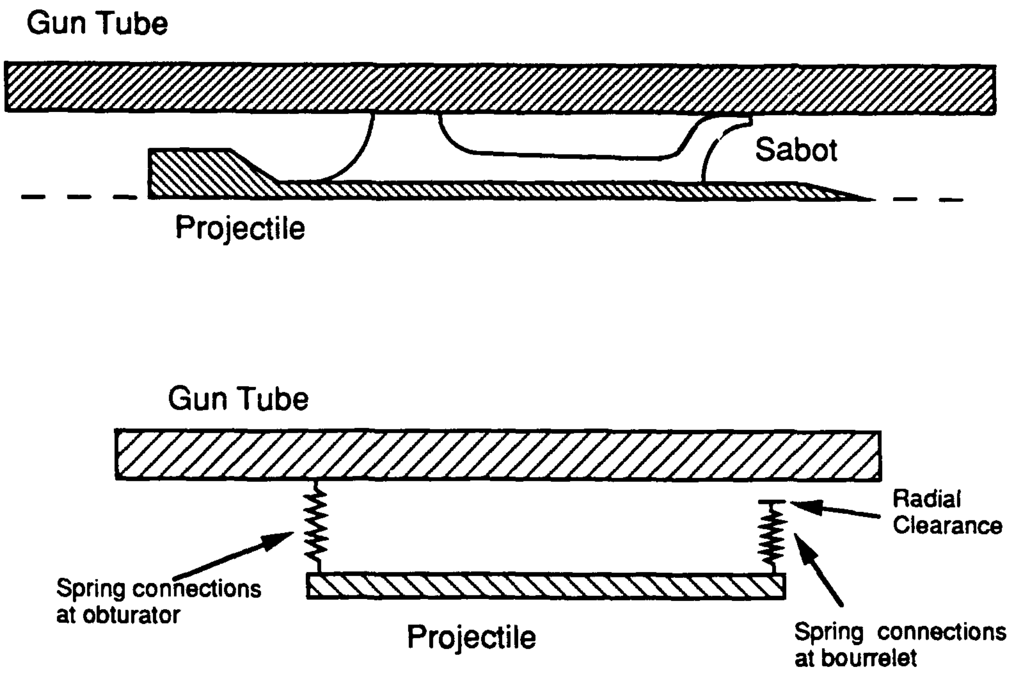

Figure 3. Simple Balloting Model for Gun Tube/Projectile Interaction.

Balloting is modeled by allowing a relative displacement between the gun tube and projectile before the spring, which is assumed connected to the projectile, contacts the tube. This simple model is directly applicable in the two-dimensional case. However, in the three-dimensional case a slight modification is introduced as illustrated in Figure 4. In the three-dimensional model, the single spring used in the two-dimensional case is replaced by a set of radial springs, each of which represents the stiffness of the bourrelet in that radial direction.

Impact between the bourrelet and the gun tube is defined to occur when the difference between the displacements of the gun tube and the projectile is greater than the clearance remaining in the direction in which the projectile displaces. In the two-dimensional model, this impact criterion can be written

$$|w_p - w_t| > \delta_r,$$

where w_t and w_p are the transverse displacements of the gun tube and projectile, respectively, and δ_r is the initial clearance in the direction in which the projectile is displaced. Since the model is two-dimensional, the projectile and tube can only displace in one plane at a time. Consequently, the criterion for detecting when balloting occurs is decoupled between the transverse planes. This means that the impact criterion can be visualized as operating on a square with the length of each side equal to the maximum diametrical clearance. This impact criterion is presented in Figure 5(a).

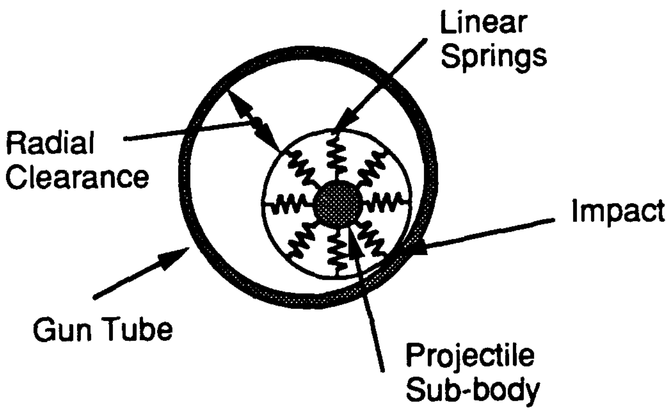

Figure 4. Three-Dimensional Balloting Model.

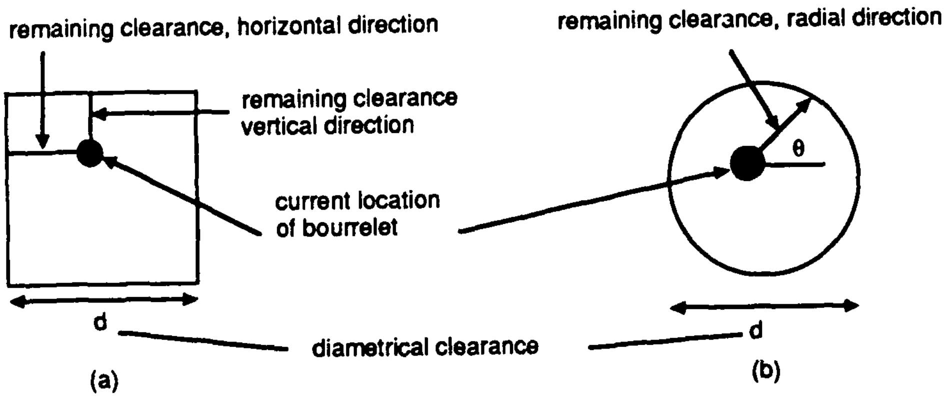

Figure 5. Geometric Representation of Impact Criterion.

Now consider the three-dimensional model. For this model, the displacement of the projectile is given by

$$\delta_p = v_p \boldsymbol{j} + w_p \boldsymbol{k} ,$$

and the displacement of the gun tube is given by

$$\delta_t = v_t \boldsymbol{j} + w_t \boldsymbol{k} .$$

Therefore, the impact criterion for the three-dimensional model is

$$|\delta_t - \delta_p| = \sqrt{(v_t - v_p)^2 + (w_t - w_p)^2} > \delta_r ,$$

where δ_r is again the initial clearance in the direction given by

$$\theta = \arctan\left(\frac{w_t - w_p}{v_t - v_p}\right).$$

However, now the equation for the impact criterion represents a circle whose maximum diameter is the diametrical clearance, Figure 5b. It is seen that this simple model requires that motion in both transverse planes must be considered when determining if impact has occurred. This coupling of the transverse planes in the impact criterion is the justification for calling models 1 and 2 three-dimensional beam models.

Another interface model, which couples the axial and torsional motion with the transverse equations of motion through the loading function, is the effect of axial displacements on offset masses. Because of the equations of motion for an offset mass, axial accelerations will generate moments causing out-of-plane forces and displacements. The combination of the above simple balloting model and the effect of offset masses serves to fully couple the equations of motion for the gun system through the loading functions.

6. GUN SYSTEM MODEL

The preceding three phases of model development are repeated for each component of the gun system which is to be included in a gun system model. Complete models for different gun systems are then obtained by combining the component models. Typically, the gun system models thus generated can be very system specific. In the above methodology, only the development of the interface descriptions determines which gun system is being modeled. Therefore, if it is desired to develop a gun system model which is as generic as possible, interface descriptions should be formulated which are not interdependent. This means that use of one interface routine should not require the use of other interface routines. If care is taken to insure that such interdependencies are eliminated, the resultant gun system model will be as general as possible.

7. SOLUTION

In most cases, it is not feasible to attempt an analytic solution of the equations of motion describing the gun system, and numerical solutions must be sought. The finite element method is one of several techniques which can be used to obtain numerical solutions of the governing equations. Application of this method to the model developed leads to a set of governing differential equations which can be expressed in matrix form as

$$\boldsymbol{M}\,\ddot{\underset{\sim}{x}} + \boldsymbol{K}\,\underset{\sim}{x} = \boldsymbol{F}\,(\underset{\sim}{x},t)\,, \tag{5}$$

where terms arising due to damping have been neglected. There are numerous numerical integration schemes available to solve this set of equations. Selection of an appropriate scheme depends upon the specific form of the coefficient matrices, $\boldsymbol{M}$ and $\boldsymbol{K}$, as well as the method by which the loads $\boldsymbol{F}\,(\underset{\sim}{x},t)$ are determined. These integration techniques are discussed in detail elsewhere (Craig 1981). The solution of these equations provides the time response of a gun system to a set of applied loads or interactions. In the next section, the proposed gun modeling approach is implemented to examine the behavior of a large caliber tank gun system.

8. RESULTS

The modeling approach discussed has been incorporated into a gun dynamics program called SHOGUN. The geometric model selected for each system component allows tapered beam elements and thus corresponds to model 2. The corresponding governing equations are therefore given by equations 1-4 with variable coefficients. This model can be used to examine the effects of a variety of gun system parameters including gun tube/projectile interaction, the effect of breech center of gravity (c.g.) offset, and the effect of tube curvature. The loading routines used at this time restrict application of the model to the 120-mm tank gun system. The results presented are the model's predictions for tube shape in the transverse planes at shot exit. These SHOGUN predictions are compared to two other gun system models, Little Rascal and DYNACODE-G/P, as well as with experimental results. The methods for obtaining the experimental data are described by Bornstein and Haug (1988). All the gun dynamics codes selected for comparison use variants of B-E theory to describe the gun system components. Little Rascal and DYNACODE-G/P use constant cross-section properties, whereas SHOGUN allows variable cross-section properties for each beam segment. Both SHOGUN and DYNACODE-G/P utilized three-dimensional beam elements. However, differences between these codes include the formulation of the mass and stiffness matrices, the type of geometric information required to describe the gun system, and the treatment of offset mass effects such as the effect of the breech center of gravity location.

In Figure 6, the predictions for the tube shape at shot exit in the vertical plane for a particular tube, denoted tube A, are presented. All three codes agree well with the experimental data. It is difficult to say if any one of the codes is better or worse than the others. The close agreement between the predictions of SHOGUN and DYNACODE-G/P is expected since they use similar governing equations and loading models. The differences are due to differences in the geometry descriptions and in the implementation of the loading models. The close agreement with Little Rascal indicates that the dynamic loading of the 120-mm gun system is basically uncoupled in the transverse directions. This lends confidence to the use of simple B-E beam theory as the governing equations.

The predictions for the tube shape in the horizontal direction are shown in Figure 7. Here the agreement with experimental data is not as good. It is hypothesized that the actual boundary conditions imposed on the motion of the breech in the horizontal direction have not been adequately modeled by any of the codes selected.

All three codes do, however, predict the same basic shape. This further reinforces the conclusion that the loads imparted to the system components in the two transverse planes are uncoupled in this gun system.

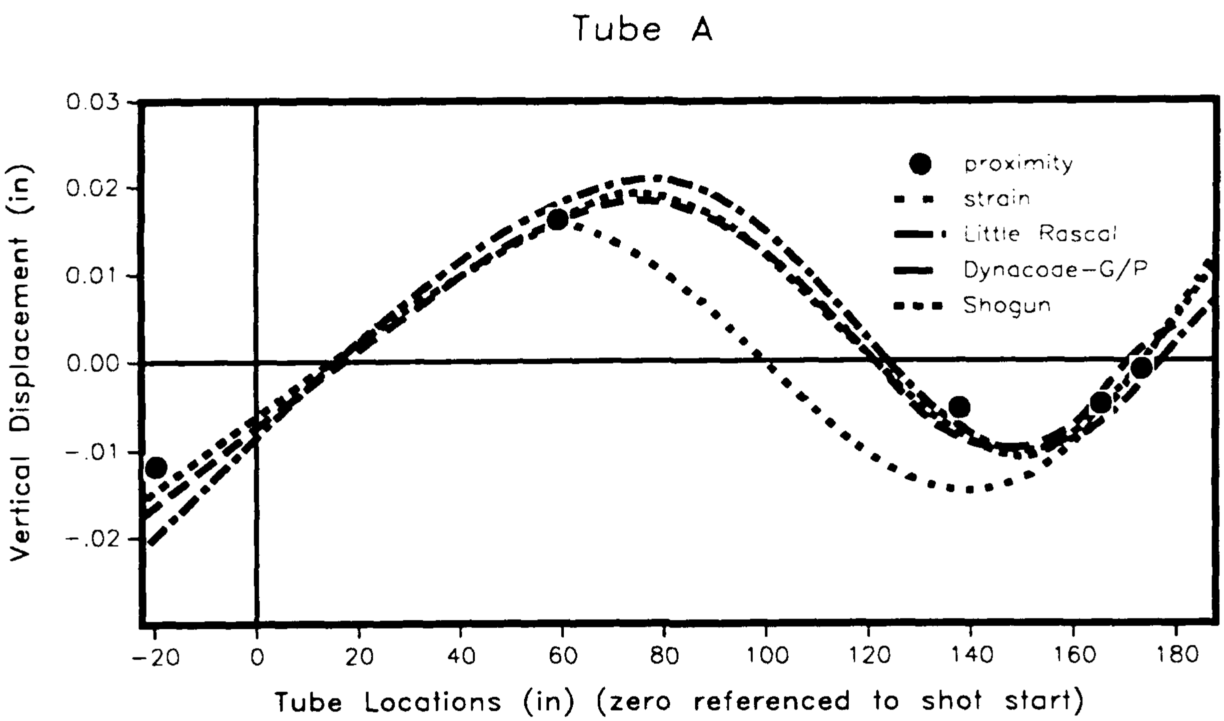

Figure 6. Tube Shape in the Vertical Plane.

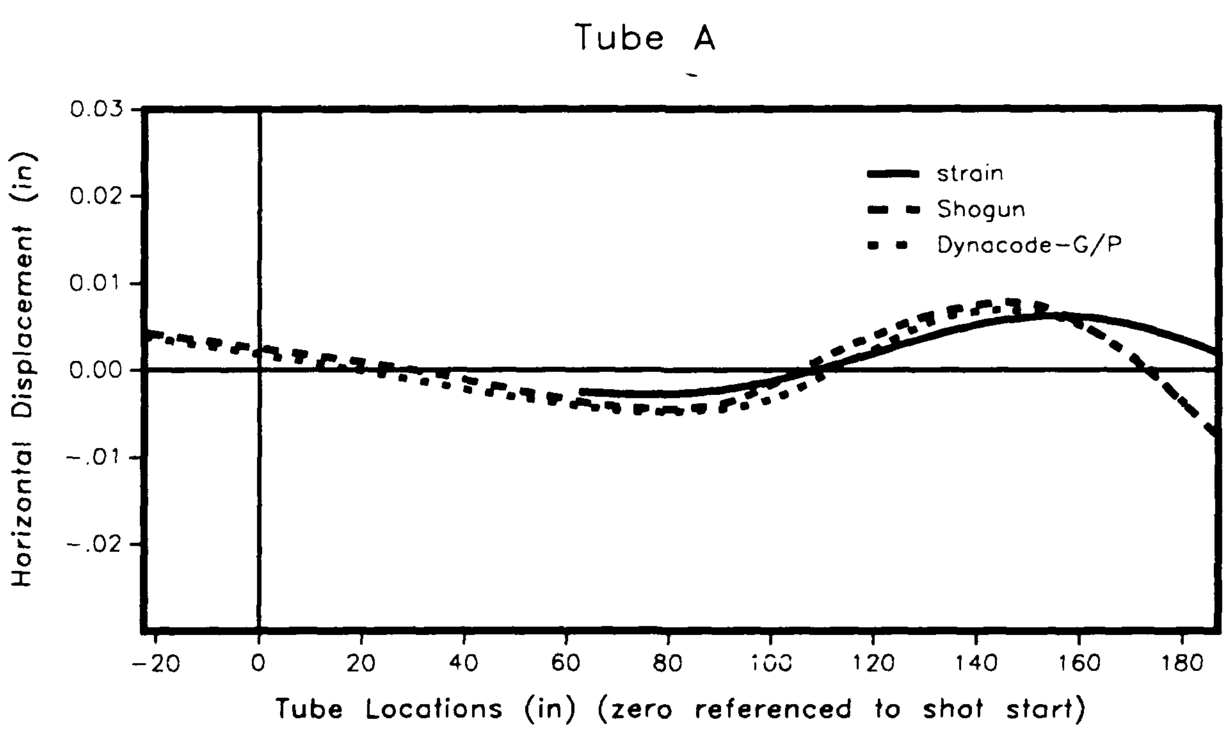

Figure 7. Tube Shape in the Horizontal Plane.

Finally, in Figure 8, the predicted tube shape in the vertical plane for a tube with a different centerline profile is presented. Again, all codes agree well with each other and with experimental data. However, comparison of Figures 6 and 8 illustrates that different responses between tubes are expected due to the effect of the tube centerline profiles.

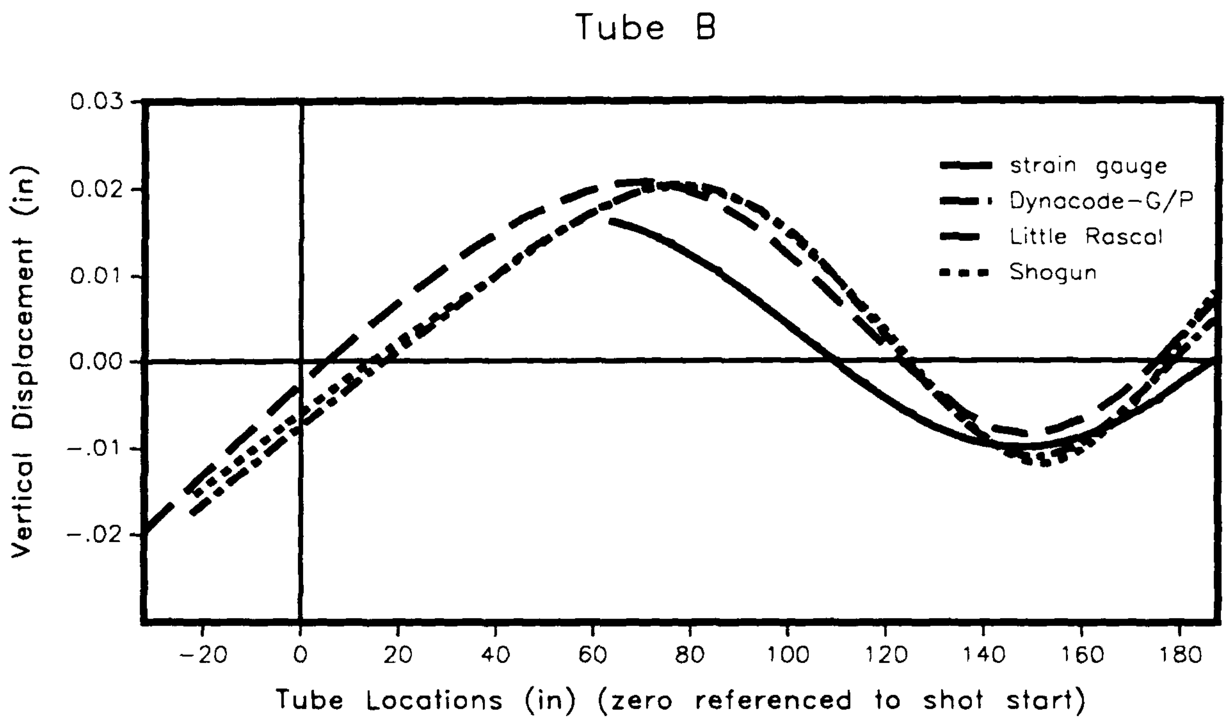

Figure 8. Tube Shape in Vertical Plane, Tube B.

9. CONCLUSIONS

A modeling approach for developing three-dimensional beam models of gun systems has been outlined. It has been shown that there are not any significant conceptual problems associated with developing these types of models. This modeling approach was incorporated into a gun dynamics program called SHOGUN. Comparisons of SHOGUN with other models indicates that this approach to modeling gun tube dynamics can provide useful qualitative predictions of the effects of various gun system parameters.

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10. REFERENCES

Bornstein, Jonathan A., and Bailey T. Haug. "Gun Dynamics Measurements for Tank Gun Systems." BRL-MR-3688, U.S. Army Ballistic Research Laboratory. Aberdeen Proving Ground, MD, May 1988.

Craig, Roy, Jr. Structural Dynamics, An Introduction to Computer Methods. New York: John Wiley and Sons, 1981.

Erline, Thomas, and Mark D. Kregel. "Modeling Gun Dynamics with Dominant Loads." BRL-MR-3683, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1988.

Hallquist, John. "Theoretical Manual for DYNA3D." Lawrence Livermore National Laboratory, Livermore, CA, March 1983.

Kingsbury H. B. "On the Motion of Rods with Initial Space Curvature." BRL-TR-2658, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1984.

Rabern, Donald A., and Kenneth A. Bannister. "Full 3-D Transient Simulations of 120-mm Tank Gun Firings." Sixth U.S. Army Symposium on Gun Dynamics, 14-17 May, 1990.

Shames, Irving, and Clive Dym. Energy and Finite Element Methods in Structural Mechanics. New York: McGraw-Hill Book Co., 1985.

Soifer, Martin, and Robert Becker. "Dynamic Analysis of the 120-mm Tank Gun." BRL-CR-576, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1987.

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